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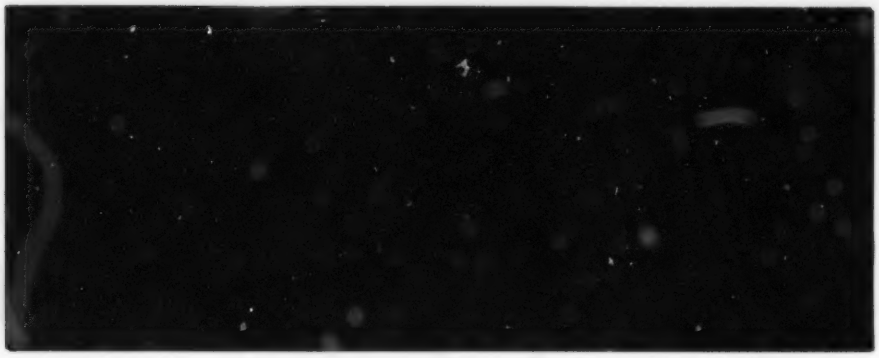

Keeping the agriculture and food industries competitive through Research, Development and Demonstration.

Final Report

1.1-21

Development of Quinoa as a New Grain Crop: Research on Agronomics and Saline Tolerance

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EXECUTIVE SUMMARY

DEVELOPMENT OF QUINOA AS A NEW GRAIN CROP: RESEARCH ON AGRONOMICS AND SALINE TOLERANCE.

by

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Quinoa (Chenopodium quinoa Willd.) is a South American grain crop which has a very high quality protein content (14% crude protein, 6% lysine). It is able to grow under semi-arid conditions on poor or saline soil and produce 800 to 1600 kg grain/hectare. Recently, lines have been produced in Colorado which will set seed in western Canada. Presently, a health food market is being developed in North America, particularly in the United States.

Eighteen varieties or lines of quinoa were purchased from Colorado for agronomic studies in Saskatchewan. Field trials on saline and non-saline soils were conducted at the Melfort Research Station of Agriculture Canada and on non-saline soil at the Crop Development Centre of the University of Saskatchewan at Saskatoon. Salinity studies were conducted in the saline facility at the Swift Current Research Station of Agriculture Canada. The field trials at both locations were severely affected by drought and heat during the last three growing seasons, but sufficient information was obtained to choose three

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varieties or lines for further study. Preliminary salinity tolerance studies indicated that quinoa had lower tolerance to salinity than barley at low salinities, but had higher tolerance at salinities above their threshold values. These studies confirmed the choice of the three lines for further study by the field trials.

Analysis of the 18 lines, three samples of 1 line grown by farmers at three locations on the prairies, and 1 sample purchased at a health food store in Saskatoon, indicated that in most cases, the germination percentages were high (>90%), the saponin contents were high (approx. 0.6%), and the crude protein contents were also very high (13 to 18%).

A survey of farmers who had grown quinoa on the prairies during the past three years showed that quinoa can provide good seed yields as a crop for western Canada. The northern portion of the grain belt appeared to be most suitable since quinoa can tolerate frost, but cannot tolerate heat, particularly during the flowering stage of maturity. They determined that emergence is reduced if the seed is planted too deep. They also felt that quinoa required further development in market establishment, processing, variety testing, herbicide development, agronomics, and as a forage for animals.

More research and development on agronomics, marketing, and processing is required before quinoa will become a cash crop for western Canadian farmers. Also, processing facilities must be available before the product can be sold in the health food market.

1.1-21

DEVELOPMENT OF QUINOA AS A NEW GRAIN CROP:

RESEARCH ON AGRONOMICS AND SALINE TOLERANCE

prepared for

Agriculture Development Fund
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ABSTRACT

Quinoa, a saline tolerant South American grain crop, containing 14% crude protein and 6% lysine, is being sold as a health food after a bitter saponin is removed from the seed coat. Its agronomics were investigated in Melfort and Saskatoon, and its salinity tolerance in Swift Current. Although drought and heat seriously affected many of the results, three lines were selected for future testing which had >90% germination, and contained about 0.5% saponin, and 17.5% crude protein. The crop can be grown successfully in the northern regions of the Saskatchewan grain belt, but marketing information and processing facilities are required.

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BACKGROUND AND OBJECTIVES

Quinoa (Chenopodium quinoa Willd.) is a South American grain crop with the ability to grow under semi-arid conditions and on poor soil (Carmen 1984). It is a member of the same plant family as sugar beets and is a close relative of lamb's-quarters. The protein quality is very good, averaging 14% protein and 6% lysine (Weber 1978). Since it grows close to the equator in the highlands of Peru and Bolivia, it was not possible, until recently, to find varieties which would set seed in western Canada (e.g., Kernan et al. 1983). A research group in Colorado developed a quinoa line which would set seed and yield acceptably in Colorado (Johnson and Croissant 1985, Johnson and McCammant 1988).

This line (Co407) grew successfully in western Canada in 1987 (Torwalt 1987, Clark 1988). As with most quinoa varieties, Co407 has a bitter saponin in the seed outer layers which can be removed by abrasive dehulling (Johnson and McCammant 1988, Reichert et al. 1986). Varieties which are very saline tolerant are available from southern Bolivia (Zambrana 1980). These have been crossed with the new Colorado line, and the crosses set seed in Colorado (McCammant 1988). Seed from Co407 and these new crosses, as well as a few other varieties, could be obtained for testing in Saskatchewan.

Seed yields have averaged over 1000 lbs/ac (1120 kg/ha). Initial sales to health food stores obtained $1.00/lb ($2.20/kg). Although the initial prices have been very high ($1.00-$3.00/lb, $2.20-6.60/kg) they are expected to drop as supplies increase. Small scale commercial processing methods will be needed soon to aid in sales and market development. Sales from 20 acres at a yield of

1000 lbs.ac at $0.50/lb would represent $10,000 new income from a small acreage.

Among the 2 million hectares of salt affected soils in western Canada (PFRA 1982) there are over 1 million hectares (2.5 million acres) of cultivated saline soils, and significant amounts are in the black soil zone where we believe quinoa is best adapted. If lines, processing methods, and markets can be developed to support production on even 25,000 acres of saline soils, this would still represent new sales of $6.25 million at a farmer sale price of $0.25/lb.

Plant species and varieties differ in their ability to withstand salinity stress. Barley varieties are generally more saline tolerant than those of wheat. Both crops respond to salt stress by a reduction in growth-vigor. That is, growth slows. This reduction in growth results in a reduced production of biomass. In most strains this reduction occurs when a threshold salt concentration is exceeded beyond which the yield reduction is proportional to increased salinity. Maas and Hoffman (1977) reported a threshold value of 6.0 mS/cm for forage barley and a reduction rate of 7.1% per mS/cm according to published test results.

A testing program for salt tolerance identification is being initiated in Saskatchewan to quantify the response characteristics of potential crop varieties for Canadian conditions. The inherent genetic tolerance of selected plants will be evaluated under standardized testing. To our knowledge, the tolerance of quinoa to osmotic and specific ion stresses has not been identified for sulfate-

based solutions. Sulfate is a common, and often the dominant anion in Saskatchewan saline soils.

The objectives of this study were to investigate the agronomics of growing quinoa in Saskatchewan, and to develop methods of growing quinoa on saline and non-saline soils in western Canada to give reasonable yields of good quality grain.

EXPERIMENTAL METHODS

The following agronomic experiments were scheduled to be conducted during the 1988 growing season; however, the extreme drought which was prevalent throughout most of Saskatchewan that year, seriously affected much of the work and arrangements were made to repeat it during the summer of 1989. Also, many of the farmers who were attempting to grow quinoa did not have much success. Therefore, it was decided to conduct the farm survey during the fall and winter of 1989-90.

Arrangements were made to purchase a quantity of quinoa Co407 and several other varieties and crosses which may be suitable for the Saskatchewan climate. The selection of these other varieties and crosses were left to the discretion of Dr. John McCammant, the director of Sierra Blanca Associates, Denver Colorado. These seeds were distributed among Dr. A. Slinkard of the Crop Development Centre of the University of Saskatchewan, Dr. L. Townley-Smith of the Melfort Experimental Station of Agriculture Canada, and Drs. D. Green and H. Steppuhn of the Swift Current Experimental Station of Agriculture Canada for their trials.

Germination tests were conducted in duplicate using 20 seeds and 3 ml of distilled water for each petri dish. The petri dishes were kept in the dark, at 20°C in an incubator, and counted after 48 hours. The hemolytic activity was determined according to the procedure of Reichert et al. (1986) and converted to % saponin (based on a standard saponin sold by Fisher Scientific Co.) using the regression equation (1) developed by Reichert et al. (1986). Crude protein (CP)

was determined at the Feed Testing Laboratory, University of Saskatchewan, by a Kjeldahl analysis for nitrogen (CP = N x 6.25).

$$\% \text{ Saponin} = 0.00675 + 0.0552HA - 0.00121HA^2 + 0.000009HA^3 \quad (1)$$

A. Slinkard (Saskatoon) was to grow all lines on non-saline soil in a randomized complete block. Selections were to be made out of these lines for seed yield, early maturity and plant characteristics (height, seed head size, etc.) and be further tested the following year. Selections were also to be tested for saponin and protein content.

L. Townley-Smith (Melfort) was to seed all lines plus kochia in many replicated microplots along a saline gradient. Dry matter yield, seed yield, soil salinity and soil nutrient status were to be measured. Small yield plots of several lines would be seeded on non-saline soil. Dry matter yield, seed yield and maturity dates were to be determined, and seed quality evaluated.

H. Steppuhn and D. Green (Swift Current) were to test at least two quinoa lines to measure germination, seedling growth, and seed yield under a variety of saline conditions using a hydroponic system in the new Saline Tolerance Facility (described in Appendix I).

M. Gimby of the Saskatchewan Research Council in Saskatoon was to conduct a survey of farmers growing quinoa in western Canada.

RESULTS AND DISCUSSION

SASKATOON

QUINOA SEED

Lines of QUINOA SEED Obtained from Sierra Blanca Associates. (Chenopodium Quinoa Willd). (The comments are those of Dr. McCammant).

"Selections originating in the southern Bolivian saltflats region.

Apelawa. (200g) Best flavored of all the large seeded varieties. May require cooler temperatures. Has considerable variation.

Calcha. (200g) Most like "Real", standard Bolivian commercial variety. Mild flavored. Hard to get good plant stands.

Kaslala. (200g) Standard variety from southern Bolivia, but no longer pure. Good flavor.

Pison. (200g) Fairly uniform, good tasting, medium sized seed. Selections originating in northern Chile, in an area similar to the Bolivian saltflats.

Isluga. (200g) First selection grown in Colorado (1982). Like Calcha but adapts better and has better flavor.

Selections originating in southern Chile, near sealevel. - Adapt best to 7000 foot regions of Colorado and to Canada. Tolerate a little more heat than saltflats quinoa. More resistant to mildew.

Cahuil. (200g) Mixed green and purple plants. Small seed with good flavor. Will probably be the choice for flour. Demonstrated best insect resistance.

Co407 or "Dave". (200g) Chosen as commercial variety in Colorado. Most consistent. Good rich flavor and high protein.

Co407 Black. (200g) Comes out of cross with wild quinoa (probably South American brought in with quinoa seed). Chewier texture with good flavor. Segregating into everything under the sun.

Single plant selections - several appear to be crosses with Co407.

SPS 86-70. (100g) A wildly segregating cross from Isluga. Lovely panicles.

SPS 86-72. (100) From Isluga. Like 86-70 but from different cross.

SPS 86-84. (100g) Selection out of Marangani, only Peruvian variety to produce.

SPS 86-102. (100g) From Tango, a northern Chilean variety.

SPS 86-116. (100g) From Amachuma. Red panicle, white seed, segregating and producing well.

SPS 86-124. (100g) A dark seed colored Chure (northern Chile).

SPS 86-130. (100g) From Linio. From highest yielding plant in 1986. Segregating in a marvellous way with every colour under the sun, early maturity.

SPS 86-133-Anjata. (100g) Anjata got mixed up in 1985. This was 1986 selection to get back to original from southern Bolivia. Did well at 8400 ft.

SPS 87-8. Selection out of Isluga. Seed colour resembles Co407 but nice large seed.

SPS 87-182. Selection out of Marangani. Good seed size, good producer."

The requested amount of seed of each variety was sent to each of the co-operators to be used in their experiments.

AGRONOMICS

Three to ten lines of quinoa were grown by Dr. A Slinkard in replicated trials at Saskatoon in 1987, 1988, and 1989. All three years were characterized by heat and drought which severely reduced emergence in 1987 and vegetative growth in 1988 and 1989. A good stand was produced in most plots in 1989 and the plants grew over 1.5 m tall. However, the primary inflorescence died back due to heat, drought or possibly a disease. This stimulated growth of secondary branches but they matured too late to set any seed. Consequently, no seed of quinoa was produced in any of the three years of testing under dryland conditions at Saskatoon. No further work on quinoa is contemplated at this time.

SURVEY

A survey of 41 farmers in Saskatchewan, 1 in Alberta, and 1 in Manitoba who had attempted to grow quinoa in 1987, 1988, or 1989 was conducted by M. Gimby of the Saskatchewan Research Council.

A summary of the survey provided some interesting information which indicated the direction future research and development work should take. Approximately 50 farmers in Saskatchewan obtained seed to grow quinoa in 1987. Only 3 grew it successfully in 1988 and only 1 in 1989. The main reasons the farmers stopped growing quinoa were crop failures due to drought, the absence of a readily available market, and the lack of processing facilities.

The normal seeding rate was about 1 lb./ac. which was successful on both summerfallow and stubble. When it was planted with a fertilizer spreader followed by a harrow, or quite shallow with a press drill, good crops were obtained. Poor emergence was observed when it was planted deeper.

Farmers have found that quinoa does not compete well with weeds and most of them controlled weeds by hand roguing. Weed competition was best when a vigorous crop emerged before the weeds began to grow. Quinoa does not appear to have many pest problems, but is attacked by flea beatles if emergence is poor. It is reasonably frost tolerant, but is susceptible to heat damage.

Quinoa appears to grow best on sandy loam or loam soils. It can be swathed after the first killing frost (dough stage), dries well in the swath, and can be threshed easily using canola combine settings to yield from 800 - 1600 lbs./ac. The seed must be cleaned and the process is very dusty. It is very difficult to separate quinoa seed from other small seeds and mouse droppings.

Several farmers felt that quinoa stubble could be used to trap snow and one observed that lamb's-quarters would not grow on soil which supported quinoa the year before, possibly an allelopathic effect. It was generally felt that quinoa had potential in Saskatchewan but required further development, in market establishment, processing, variety testing, herbicide development, agronomics, and as a forage for livestock.

A copy of the questionnaire used in the survey, containing summarized answers, is included in this report as Appendix II.

ANALYSIS

All 18 quinoa varieties received from Colorado and a number of samples of Co407 grown on the prairies were analyzed for % germination, hemolytic activity, % saponin, and % crude protein (dry matter basis) (Table 1).

Table 1. Saponin and Crude Protein Content and % Germination of Quinoa. Seed

Variety	Germination (%)	Hemolytic Activity	Saponin (%)	Crude Protein (%)
Apelawa	93	15.2	0.60	16.8
Calcha	100	18.8	0.68	17.1
Kaslala	98	13.7	0.56	15.9
Pison	100	13.7	0.56	16.7
Isluga	100	18.8	0.68	17.1
Cahuil	98	17.0	0.64	16.9
Co407	93	10.0	0.45	17.4
Co407-black	95	11.1	0.48	16.8
SPS 86-70	45	11.1	0.48	17.7
SPS 86-72	93	11.6	0.50	16.4
SPS 86-84	95	15.2	0.60	18.5
SPS 86-102	95	17.0	0.64	17.2
SPS 86-116	78	18.8	0.68	15.8
SPS 86-124	100	17.0	0.64	18.0
SPS 86-130	80	15.2	0.60	15.4
SPS 86-133-Anjata	55	15.2	0.60	15.7
SPS 86-8	98	15.2	0.60	17.0
SPS 87-182	98	18.8	0.68	17.9
Leroy, SK	95	9.4	0.43	14.1
Oyen, AB	100	6.9	0.33	17.7
Artesian*	98	3.8	0.20	17.5
North Battleford, SK	95	12.4	0.52	13.3

* Commercial quinoa purchased in Saskatoon, SK

MELFORT

1988

Each of 12 lines of quinoa and kochia were planted by Dr. L. Townley-Smith in 1 m long rows in each of 30 replicates on a saline gradient. Lack of moisture (growing season rainfall was only 35% of normal until the end of July) prevented germination of all but a few seeds. Seventeen replicates contained plants, so single plant size was recorded and soil samples taken to determine soil salinity. Most of the plants were located in the parts of the plot area that had low salinity. The relationship between salinity and plant growth and variety could not be determined (Table 2.)

Germination in the non-saline variety test was low and uneven. Plots were too variable to get meaningful results and emergence was too slow to allow most plants to reach maturity. As a result no data was collected.

Table 2. Quinoa size and soil salinity at Melfort in 1988.

Soil Conductivity (mS/cm)	Plant Height (cm)	Weight (g)	Weight of Reproductive Structures (g)
0.26	58	47	15
0.33	4	29	12
0.36	50	20	9
0.36	61	44	23
0.39	70	49	32
0.46	63	26	9
0.51	59	114	81
0.57	58	35	17
0.61	56	47	21
0.64	91	190	82
0.80	79	109	34
0.94	56	33	18
0.98	37	8	2
1.10	53	106	61
1.10	42	42	21
2.50	43	25	11
10.95	2	13	6

1989

Experiments were carried out at Melfort to test salinity tolerance, dryland production and seedling emergence. No seed was obtained from the dryland production or the salinity tests. Both were reseeded after poor initial germination and were not able to mature sufficiently to form seed. The emergence test was conducted in a growth chamber and was not kept until maturity.

Dryland Study

The Texas kochia produced significantly more dry matter than all quinoa varieties or crosses (Appendix III, Table 1). Co407, Cahuil, SPS 86-72, Pison, Apelawa, and Calcha produced the most dry matter and SPS 87-8, SPS 86-116, SPS 87-182, SPS 86-133, and SPS 86-70 were low producers in 1989.

Salinity Study

Texas kochia was significantly more capable of establishment and production in saline soils than any quinoa variety (Appendix III, Table 2). Quinoa varieties differed in their ability to establish and to produce under various salinity levels with Co407, SPS 86-84, Co407-black, Cahuil, SPS 86-124, and Pison showing the highest production in the saline area. Isluga, SPS 87-8, SPS 86-116, SPS 87-182, SPS 86-133, and SPS 86-70 were the lowest dry matter producers.

Cultivars, such as Cahuil and Co407, which did well under dryland conditions also tended to do well in the saline area. They also showed strong emergence when planted at a depth of 4 cm even though their seed was very small. Establishment may be better at this depth when soil moisture is poor.

Emergence Study

Plant height and emergence was affected indirectly by seeding depth and also by cultivar (Appendix III, Tables 3 and 4). As expected, emergence decreased as seeding depth increased, particularly at the 8 cm depth (Appendix

III, Figure 2). Cahuil, Isluga, and Co407 had significantly better emergence than SPS 86-116 and Apelawa. Emergence of Isluga and Cahuil increased and Co407 remained constant up to the 4 cm depth while Apelawa, SPS 86-124, and SPS 86-116 decreased after the 2 cm depth. Isluga emergence dropped only slightly through to the 8 cm depth (Appendix III, Figure 2). Mean plant weight was not significantly affected by depth or cultivar.

Currently there is some indication that quinoa can be grown in slightly to moderately saline areas. It has high dry matter yields, even in dry growing seasons and its reported maturity is short enough for Saskatchewan conditions.

SWIFT CURRENT

Initial germination was used to indicate the relative salt tolerance among the 18 quinoa lines. The germination status as determined by the number of germinated seeds (radicle length >= 5 mm) and their relative vigor (rated from a low of 0 to a high of 9) was evaluated and averaged (Appendix IV, Table 1). Conversion of the germination numbers to percent permitted the genetic lines to be arrayed by rank (Appendix IV, Table 2). SPS 86-84, SPS 86-124, Co407-Black, and Co407-Dave were the 4 highest ranking lines and SPS 86-130, SPS 86-133, SPS 86-70, and Apelawa were the 4 lowest ranking lines.

In order to calculate comparative values indicative of germination in response to salinity, the mean count resulting from the first and second level of salt concentration was used as a scaling denominator for the remaining counts. This resulted in germination percentages relative to their performance in little or

no salt and, as shown in Table 3 of Appendix IV, permitted the valid salt tolerance ranking amongst the 18 lines. This method resulted in SPS 86-84 being ranked as the most salt tolerant of the genetic lines. The Co407-Dave line, which has been recommended for commercial production in Colorado, ranked in the upper half of Table 2 and the median in Table 3.

Co407-Dave outperformed Kaslala in an extended germination test at the higher salinity levels, although total germination numbers of the two lines exhibited much less divergence at the end of the experiment Appendix I, Figure 1).

A shoot biomass test was conducted on the quinoa lines Co407-Dave and SPS 86-84 compared to Harrington barley. These two lines were chosen since SPS 86-84 gave the best results in the germination tests and Co407-Dave is the line presently being grown commercially in the USA. The barley was in the 5-leaf stage 30 days following seeding, while the quinoa at that time showed about 12 true leaves. Typical of an indeterminate type of plant growth, quinoa continued to produce new shoots and leaves as the deadline for harvest neared. It became evident that validly comparable grain yields would not be possible, leaving comparisons between plant height and shoot biomass as the lone measures of salt tolerance. Quinoa plant heights were greater than those of Harrington barley (Appendix IV, Table 4) as was the dry matter biomass production (Appendix IV, Table 6).

The salt tolerance response functions together with data points averaged from the three test replications indicate that beyond their respective thresholds,

quinoa shoot production of the two genetic lines, Co407-Dave and SPS 86-84, react less negatively to increasing root-zone salinity than the reaction from Harrington barley. However, the threshold EC of barley is greater than those of SPS 86-84 and Co407-Dave being 13.5, 10.1 and 5.9 dS/m respectively.

This suggests that barley may outproduce quinoa at low salinity but that quinoa may outproduce barley at salinities above their threshold values.

CONCLUSIONS AND IMPACT

Personal communication from Sierra Blanca Associates in Denver, Colorado indicates that the Quinoa Corporation in Boulder, Colorado cannot import enough quinoa from South America to satisfy the health food market in the United States. They have also commented that the quinoa line, Co407, which they have attempted to grow commercially has not been accepted as well as Isluga by a taste panel.

The results of these preliminary trials indicate that quinoa has some salinity tolerance and will germinate and produce biomass in Saskatchewan. Several lines, particularly SPS 86-84, a Peruvian variety from Marangani, but including Co407, show fairly good salinity tolerance, but Isluga and lines crossed with Isluga do not. This indicates that more work is required to determine if Isluga will produce well on non-saline soil and other lines such as Co407 or SPS 86-84 would be useful for saline soils.

The survey shows that quinoa (Co407) will produce grain in Saskatchewan, is somewhat frost tolerant, but cannot stand much heat, particularly in the flower stage of maturity. It appears as though quinoa could become a cash crop for small acreages in the northern portion of the Saskatchewan grain belt.

It is evident that more agronomic studies are required to determine the best growing methods and the best lines for Saskatchewan farmers to use. Also, the survey indicates that marketing and processing information and processing facilities are required before farmers will seriously attempt to grow quinoa again in Saskatchewan.

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APPENDIX I

SWIFT CURRENT SALT TOLERANCE TESTING FACILITY

An Agricultural Development under the Canada/Saskatchewan Economic and Regional Development Agreement (ERDA)

Assisted by: Agricultural Development Branch
Prairie Farm Rehabilitation Administration
Research Branch

Designed & Constructed by: Agriculture Canada Research Station,
Swift Current, Saskatchewan

I. GENERAL DESCRIPTION

Salt tolerance in agricultural crops relates primarily to functions of genetics. One crop, or variety, produces better than another in saline environments, because of its inherent ability to better cope with salt stress. The Swift Current Salt Tolerance Testing Facility offers a range of test options, a consistent control over ambient conditions, and a large growth space previously not available in Canada. This rigor in testing should permit evaluation of the relative level of salt tolerance inherent in all Canadian crop varieties with a high standard of precision.

The Swift Current Facility possesses the capability to simultaneously test the salt tolerance of crops at three different growth stages: germinating seeds, seedlings, and mature plants. Nutrient and salt solutions are provided hydroponically in all three test modules. Solutions automatically bathe the root zones of the test plants anchored in medium-textured quartz sand, according to pre-set irrigation and drainage schedules. The entire facility is housed in a thermally-controlled greenhouse which permits year-round testing, including a yearly radiation cycle parallel to Canada's natural growing season. The mature plant component is even large enough to compare seed production from tall crops such as corn, reed grass, and shrubs.

The Facility also contains space for additional experiments to solve specific salt-related problems. For example, a study involving the effects of excessive sodium in irrigation waters and funded by the Saskatchewan-Canada Irrigation Agreement authority is scheduled to utilize part of the facility.

II. PRIMARY TEST OBJECTIVES

Tests in other countries have shown that crop varieties respond to salt stress following genetically-controlled patterns. Salt stress does not affect growth until a threshold level of salt concentration is reached. Generally, increasing stress beyond this threshold reduces crop growth and yield according to consistent patterns of decline dependent only on growth stage and genetic tolerance. That is, a variety of barley might show no effect of total salt stress until, say, concentrations exceed 6,000 ppm. Thereafter, each additional 1000 units of dissolved salt, say, from 6,000 to 7,000 ppm, from 7,000 to 8,000 ppm, from 8,000 to 9,000 ppm, etc. results in a uniform reduction in crop yield, say, 20%, 40%, 60%, etc.

The primary objective of the Swift Current Facility will be to identify these salt tolerance patterns for Canadian varieties and cultivars. This knowledge will assist in the interpretation of results from field trials involving questions pertaining to relative salt tolerance. Knowing the basic genetic response of a crop to salt stress permits better evaluation of agronomic and climatic influences on plant growth in saline environments.

III. STRUCTURAL SPECIFICATIONS

Material:	Double wall acrylic sheeting on a galvanized metal frame; diffuse solar penetration
Transmissivity:	Approximately 0.8.
Upper Floor:	Two growth rooms with a total floor area of 195.6 m^2 (88 by 24 ft.), and variable total height from 3 m at the sides to 4.9 m at the gable-roof; height between floor and supplementary lights fixed at 2.5 m.
Lower Floor:	Service basement (full-size), housing solution supply tanks, pumps, germinator, controls, electrical, preparation bench, etc.
Ventilation:	(1) Full-length, gable-top windows automated with respect to air temperature, outside wind velocity and direction, inside air circulation fans, and (2) automated evaporative coolers.
Solar Radiation Shielding:	Automated, horizontally-spread solar curtains consisting of porous-weaved, reflective aluminum strips.

IV. PLANT GROWTH STAGES TESTED

Mature Plants

Upright, polyethylene growth tanks consisting of cylinders, 1.0 m tall and 0.95 m in diameter; each tank sand-filled with high-grade quartz (99.8 % pure) of 0.3 to 1.0 mm nominal particle diameter; each tank with a 0.7 m^2 upper surface growth area, and approximately 0.65 m^3 of sand, solution, and root volume; tanks surface irrigated and bottom drained; each tank supplied individually with solution delivery from 55 separate storage vessels; evapotranspiration from each tank individually monitored.

Seedlings

Upright, truncated, polyethylene cone pots, 0.3 m tall and 0.34 m upper diameter; sand-filled with high-grade sand (0.2 to 1.0 mm nominal particle diameter); 54 pots each surface irrigated and bottom drained; nine randomly placed pots supplied from one solution supply.

Seed Germination

Environmentally-controlled growth cabinet; 54 germination dishes, designed to maintain constant solution concentrations.

V. ENVIRONMENTAL MEASUREMENT AND CONTROL

Controls

Environmental and operational control in the growth rooms is maintained with the aid of a General Electric Series Six Electronic Controller. Ambient air temperature and radiation intensity are automatically monitored and adjusted by controlling circulating fans, evaporative coolers, solar curtains, gable vents, supplemental sodium lamps (Phillips high-pressure), and steam heated radiators. Reference and set points are adjustable depending on desired environmental conditions. Irrigation scheduling of the salt and hydroponic solutions along with daily evapotranspiration monitoring are also programmer controlled.

Controls for the germinator form a separate component of the growth cabinet and provide adjustment of the illumination, temperature, and humidity.

Growth Room Uniformity Tolerances (Spatial variation from set points)

Artificial Light:	Intensity +/- 5%; Day length +/- 1%; Quality +/- 0.1%
Air Temperature at Plant Canopy:	+/- 1.0°C
Carbon dioxide concentration:	+/- 1.0%, approx. = to outside atmosphere
Nutrient concentration:	+/- 2% estimated
Salt and Specific ion concentration:	+/- 2% estimated
Water Supply:	+/- 0.5% in wet-dry cycles
Humidity:	+/- 3%,approx., Range approximately 30% of outside atmospheric variation

Germinator Uniformity Tolerances (Spatial variation from set points)

Artificial Light:	+/- 8%
Temperature:	+/- 0.5°C
Humidity:	+/- 5% at 90% Relative Humidity
Salt Concentration:	+/- 2% est.

VI. TENTATIVE CROP TESTS

Salt tolerance testing in which cooperative interest in the facility has been expressed include the following crops and studies:

* Irrigated spring wheat varieties,
* Selected geno-types of alfalfa,
* Selected geno-types of flax and canola,
* Rhizomes and seed propogation of selected forage grasses,
* Effects of chemical amendments for sodic soils,
* Selected types of kochia and quinoa.
* Woody shelterbelt species

June 1988
Swift Current Agriculture Research Station
Director B.H. Sonntag
Engineering Section Head F.B. Dyck
Research Scientist H. Steppuhn
Design Engineer D. Chevalier

APPENDIX II

QUINOA QUESTIONNAIRE

1. *Where did you purchase Quinoa seed?*

   Some farmers acquired Quinoa seed from Colorado State University (variety #407D). G. Clarke, Manitoba supplied most of the farmers surveyed with 407D.

2. *What was the Quinoa variety?*

   Many farmers could not remember the seed variety they used, those who did indicated 407 D.

3. *How many years have you grown Quinoa?*

   Farmers began to grow Quinoa in 1987. In 1988 the survey indicates that as many as 50 Saskatchewan farmers attempted to grow the crop (plot size ranged from a single garden row to 35 acres). In 1988 Saskatchewan experienced a severe drought which wiped out most of the Quinoa crops (only 3 Saskatchewan producers grew the crop on a field scale successfully (>½ acre), only 1 farmer was found to be growing the crop on a field scale in 1989.

   NOTE: farmers indicated that a crop failure caused by drought in 1988 coupled with absence of a market and the lack of processing facilities as the reasons for not continuing with the crop.

SEEDING

4. *Was Quinoa planted on stubble? Summerfallow?*

   Quinoa was usually planted on summerfallow but was also grown successfully on stubble.

5. *Was the land weed free? and*
6. *What was the seeding date?*

   Seeding dates ranged from late April until mid June.

7. *What was the seeding rate?*

   Seeding rates ranged from 0.75-6.0 lbs acre (usually 1 lb/acre). The heavier seeding rate was an attempt at greater weed competition.

8. *What was the seeding depth?*

9. *What seed implement was used?*

Most often seeding was done with a fertilizer spreader, then followed with harrows. Shallow seeding with press drills was also successful. Discers and air seeders placed the seed too deep which resulted in poor crop emergence.

10. *What were the climatic conditions for the field with Quinoa in 1988?*

The farmers indicated that climatic conditions favourable to small seeded crops such as canola are also suited to Quinoa.

11. *Was a germination test carried out on the Quinoa seed? If so, what were the results?*

12. *What sort of germination occurred once the crop was planted?*

13. *Describe the soil that the Quinoa was planted on.*

14. *Did you take soil tests? and*
15. *Did you apply fertilizer? If so, how much? According to soil tests?*

Farmers who successfully grew Quinoa generally did not soil test and did not apply fertilizer to the crop.
One organic farmer applied molasses/kelp as fertilizer.

16. *Did you encounter any special problems related to planting the crop?*

Care must be taken not to plant the crop too deep.

17. *Did you develop any special techniques related to seeding the crop?*

Some farmers mixed the Quinoa seed with fertilizer or sterilized mustard to assist the seeding operation. Row cropping (by blocking seed implement runs) and regular cropping were tried by farmers. The row crops grew taller and were usually hand weeded.

18. *List the cropping operations for 1988.*

PEST CONTROL

19. Were you able to control weeds successfully? and
20. Did the crop offer good competition against the weeds? Explain.

Quinoa does not compete well with weeds. Weed competition was best when a vigorous crop emerged before the weeds began to grow.

21. How did you control broadleaf weeds? Explain, and
22. How did you control grassy weeds? Explain.

Some hand roguing was used to control the weeds on small plots. Hand roguing was used when Quinoa was row cropped.

23. Did you encounter insect pests? If so, explain how you controlled them.

Flea Beetles were a problem if the emerging crop was weakened by drought or cold stress in the spring (poor germination).

24. Did you encounter any other kinds of pests i.e., birds? If so, explain how you controlled them.

Other pests did not cause problems. Some farmers said that birds were attracted to the colourful plants but did not like the taste of the seed.

25. Did you develop any special techniques with regard to pest controlling the Quinoa crop?

None.

26. Was the crop affected by any disease? If so, explain.

No.

27. Did you develop any techniques for disease control?

None.

CLIMATE

28. Describe your observations of how climatic conditions affected the crop throughout the growing season. i.e., drought stress, flowering, heat stress.

A light stand caused by poor germination in early spring is very susceptible to weed and flea beetle infestation.

Seedlings can tolerate some frost (-3°C). Some farmers feel that the extreme heat resulted in the heads not filling. One farmer said that singular Quinoa plants (as in row cropping) do well while crowded ones do not. He thought that under crowded conditions the plant expends so much energy trying to get sunlight that it doesn't set seed. Other farmers felt that if the crop was well established it could tolerate the drought quite well.

A killing frost in the fall (>-5°C) stops the plant from growing and aids in the dry down which enables the harvest operations.

SOIL CONDITIONS

29. Under what soil conditions did the crop seem to grow best? Explain.

The best success was achieved on sandy loam or loam soils. Farmers noted that the crop grew best in low spots with adequate moisture.

A farmer who grew the crop on a clay loam soil saw better germination on the headlands where increased packing occurred.

SWATHING

30. Was the crop swathed or straight combined?

Most crops were swathed and dried in the windrow, however some crops were straight combined.

31. How tall was the crop when cut?

The crop stood 2-6 ft depending on moisture and heat and whether row cropped or conventionally seeded.

32. If the Quinoa was swathed, what date?

Mid September to mid October after the first killing frost.

33. Did you encounter any problems with regard to cutting the crop is, shattering, etc.?

Only one farmer surveyed had problems with shattering.

34. *What stage of maturity was the straw and grain at cutting time?*

Just after the seed is in the dough stage when the straw is still tough.

35. *Had the crop lodged at cutting time?*

Not usually a problem.

36. *Was there any frost damage?*

No frost damage indicated.

37. *Did you develop any special techniques for cutting the crop?*

None.

38. *How long did the crop lay in the window before drying?*

Approximately 2 weeks.

39. *Was there any damage to the crop while drying in the windrow i.e., bleaching of the seed, sprouting, etc.?*

If heavy rain causes the heads to touch the ground Quinoa will quickly begin to sprout.

COMBINING

40. *What date was the crop combined? and*
41. *What did the crop yield?*

800 - 1600 lbs/acre uncleaned.

42. *What was the moisture content?*

The moisture test for canola was used.

43. *Was the crop easy to thrash compared to other crops? More difficult? Explain.*

Most farmers indicated that Quinoa was very easy to thresh, however, one farmer said that the very light seed caused separation problems which resulted in a lot of foreign material in the sample.

44. Describe your combine settings.

Generally, most farmers used a canola setting for the combine.

45. Describe any problems which occurred while combining Quinoa.

One farmer said tough Quinoa stems caused plugging above the straw chopper on a White combine.

46. Did you develop any special techniques for combining Quinoa?

None.

CROP RESIDUE MANAGEMENT

47. What did you do with the crop residue in the fall?

The crop residue was usually worked into the soil in the fall.

48. Did you encounter any problems when dealing with the residue i.e., plugging tillage equipment, etc.?

49. Did the residue break down quickly?

Quinoa residue decomposed as quickly as most other crop.

50. Would Quinoa stubble be useful for leaving strips to trap snow?

Farmers generally agree that Quinoa stubble would trap snow

51. Describe the condition of the stubble after the crop has been harvested i.e., does Quinoa appear to dry out the soil more than other crops?

Many farmers indicated that the soil after growing Quinoa appeared to be more dried out than when other crop where grown. One farmer said that lamb's-quarters did not grow on the field that had been seeded to Quinoa the year before (allelopathic effect?).

HANDLING AND STORAGE

52. *Did you encounter any problems related to handling and storage of Quinoa i.e., loading problems, dust, heating, etc.?*

No problems handling and storing Quinoa except that it is very dusty (probably a mask should be worn). One farmer noted that the dust caused a drying of the throat and bad taste.

53. *Did you develop any special techniques for handling and storage of Quinoa?*

Some farmers spread the crop on a bin floor and then turned it with a shovel to assure appropriate dryness.

54. *Did you clean the seed yourself? What equipment was used?*

One farmer used a hand sample cleaner from the elevator. Some used a fanning mill for cleaning.

55. *Did you encounter any problems when cleaning the seed i.e., contaminants that are hard to separate, equipment problems, etc.?*

Mouse droppings, and small seeds the same size as the Quinoa are very difficult to separate out.

56. *Did you develop any special techniques for cleaning the seed?*

One farmer set up a pearler in concert with a commercial seed cleaning plant.

57. *Do you think that Quinoa has a potential as a crop in Canada?*

58. *What sort of information particularly do you need to have?*

Farmers generally agreed that Quinoa has potential as a crop in Saskatchewan if further development is carried out in the following areas:

- Market establishment
- Processing and seed cleaning
- Variety testing for Saskatchewan conditions
- Herbicide development
- Agronomic research
- Research into livestock feed potential.

APPENDIX III

Dry matter production of quinoa cultivars in response to dryland, salinity and seeding depth.

Report to
The Saskatchewan Research Council

Prepared by
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Introduction

Quinoa is native to the Andes mountains where it has been cultivated for centuries. It is a nutritionally valuable crop with protein levels above wheat and an amino acid compositon similiar to milk. The seed may be cooked, ground for flour, or roasted. The plant may also be used for animal feed. Its low water requirement, 90 to 125 days to maturity, and tolerances of fall frosts make quinoa a crop that could be produced in Saskatchewan.

Experiments were carried out at Melfort to test salinity tolerance, dryland production and seedling emergence. No seed production was obtained from the dryland production and salinity tests as they were reseeded after poor initial germination. The emergence test was conducted in a growth chamber and was not kept until maturity.

Methods

The dryland experiment was a randomized complete block design, replicated three times with plots of 3 x 0.75 meters. It was seeded 1.5 to 2 cm deep with a double disc press drill with 25 kg/ha of seed placed phosphate. The initial seeding failed emerge evenly due to uneven packing and dry conditions. The second seeding, on July 3,1989, was seeded similarly with double packing. Total above ground plant material was harvested by hand on September 26.

The salinity experiment was seeded in a randomized complete block design, replicated twenty seven times. The reps were distributed in four salinity zones, 0-2, 2-4, 4-8 and 8+ mSe, which were identified in the spring with an EM 38. The quinoa was hand seeded approximately 1.5 to 2.0 cm deep in 15 cm square plots on July 4, 1989, following the failure of the earlier seeding. Total above ground material was harvested on September 29.

The emergence experiment was carried out in growth chambers. The initial conditions were 14 hours of bright light and temperatures of +15 C maximum and +6 C minimum. After 17 days the maximum temperature was increased to 20 C to promote growth. Seeds from 6 varieties were placed in a packed soil mix of 75% clay loam and 25% peat by volume, and covered with either 1, 2, 4 or 8 cm of packed soil. Each pot was covered with 1 cm of loose peat and kept moist. During the test, emergence and total plant height was recorded, and at four weeks above ground plant material was harvested and plant height measured.

Dryland production results

Texas kochia production was significantly better than all quinoa varieties (Table 1). The cultivars 407, Cahuil, 86-72, Pison, Apelawa and Calcha produced the most dry matter and 87-8, 86-116, 87-182, 86-133 and 86-70 were low producers in 1989.

Table 1. Effect of varieties on total plant material in dryland quinoa at Melfort, 1989.

Cultivar	Total plant material (kg/ha)
Kochia	13200
407	8420
Cahuil	6380
86-72	6340
Pison	6090
86-130	5570
Apelawa	5510
Calcha	5400
86-84	5360
407-black	5180
86-124	4970
86-102	4860
Isluga	4820
Kaslala	4670
87-8	4010
86-116	3810
87-182	3170
86-133	3070
86-70	2680

LSD(0.05)=3060

Saline tolerance results

Texas kochia was significantly more capable of establishment and production in saline soils than any quinoa varieties (Table 2). Quinoa varieties differed in their ability to establish and to produce under various salinity levels with the cultivars 407, 86-84, 407-black, Cahuil, 86-124 and Pison showing the highest production in the saline area. Isluga, 87-8, 86-116, 87-182, 86-133 and 86-70 were the lowest dry matter producers.

Emergence test results

Plant height was affected by seeding depth and cultivar (Table 3). Plant height decreased as seeding depth increased (Figure 1). Cultivar differences are shown in Table 4.

Emergence was affected by seeding depth, cultivar and there was a seeding depth-cultivar interaction (Table 3). As expected, emergence decreased as seeding depth increased, particularly at the 8 cm depth (Figure 2). Cahuil, Isluga and 407 had significantly better emergence than 86-116 and Apelawa. Emergence of Isluga and Cahuil increased and 407 remained constant up to the 4 cm depth while Apelawa, 86-124 and 86-116 decreased after the 2 cm depth. Isluga emergence dropped only slightly through to the 8 cm depth (Figure 2).

Mean plant weight was not significantly affected by depth or cultivar.

Table 2. Effect of cultivar and salinity on total plant material in quinoa salinity test at Melfort, 1989.

Cultivar	Dry matter production (g/plot) Salinity (mSe)					Emergence (number of reps)[1] Salinity (mSe)			
	0-2	2-4	4-8	8+	Mean	0-2	2-4	4-8	8+
Kochia	136	165	282	221	214	3	7	10	4
407	79	46	39	0	41	4	7	8	0
86-84	32	55	36	10	37	4	8	9	1
407-black	32	40	34	6	30	4	8	8	1
Cahuil	17	29	43	0	27	3	8	10	0
86-124	19.	22	37	1	22	3	5	8	1
Pison	19	18	26	0	18	4	7	7	0
86-116	17	23.	19	5	17	3	8	6	1
86-130	17	23	21	0	17	3	6	7	0
86-102	5	6	35	0	16	4	4	8	0
86-72	28	12	14	10	15	3	7	6	1
Calcha	19	8	18	13	14	2	7	7	1
Apelawa	13	9	24	0	14	3	4	9	0
Kaslala	19	20	13	0	13	3	6	7	0
Isluga	10	7	22	0	12	1	5	6	0
86-70	15	13	12	0	11	3	6	7	0
87-182	12	9	15	0	10	4	6	8	0
87-8	1	11	16	0	9	3	5	6	0
86-133	4	1	5	0	3	2	2	7	0

1 number of reps where cultivar grew out of a maximum of: 0-2 = 4, 2-4 = 8, 4-8 = 10 and 8+ = 4.

Table 3. Analysis of variance for plant height, plant weight and emergence, for quinoa emergence test at Melfort, 1989.

Source of variance	Plant height (cm)	Weight (gm/plant)	Emergence %
Depth (D)	**	n.s.	**
Cultivar (V)	*	n.s.	*
D X V	n.s.	n.s.	*

** significant at p< .001

* significant at p< .05

Table 4. Effects of cultivar on plant height (cm) in quinoa emergence test at Melfort, 1989.

Cultivar	Plant height (cm)
86-116	4.9
Cahuil	5.4
Isluga	5.5
86-124	5.6
Apelawa	5.7
407	6.0
Mean	5.5

LSD(0.05) = 0.7

Table 5. Effect of depth and cultivar on emergence (%) in quinoa emergence test at Melfort, 1989.

Cultivar	Depth (cm)				
	1	2	4	8	Mean
86-116	74	72	50	30	56
407-89	88	94	85	22	72
Cahuil	84	78	100	25	72
Apelawa	58	74	58	22	53
Isluga	75	75	88	56	73
86-124	88	70	55	30	63
Mean	78	77	73	31	65

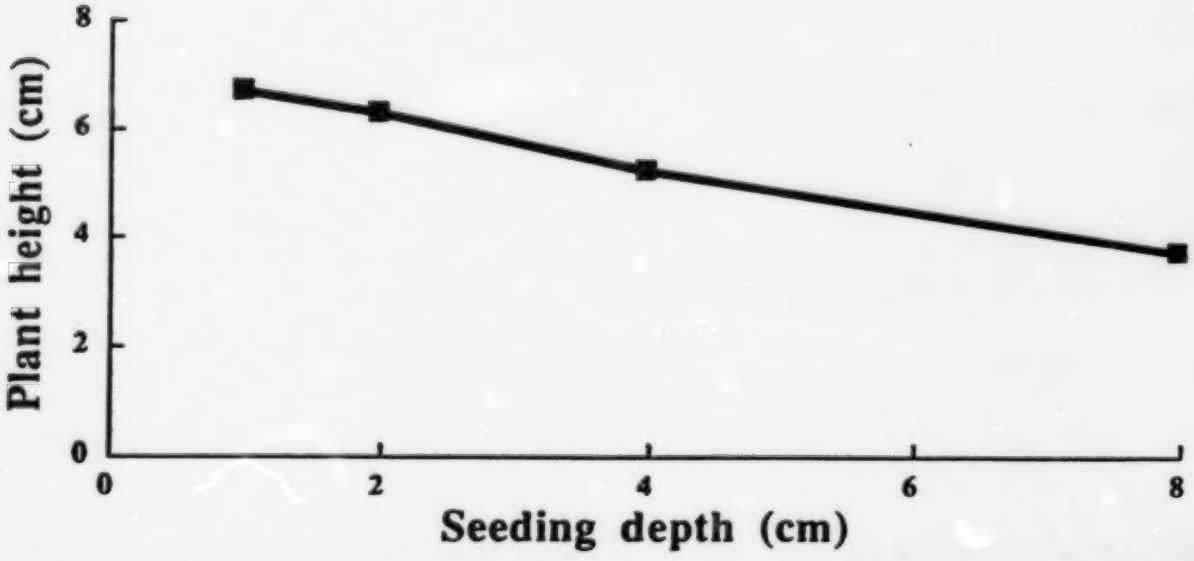


Figure 1. The effect of seeding depth on plant height at four weeks after seeding of quinoa grown in the growth chamber.

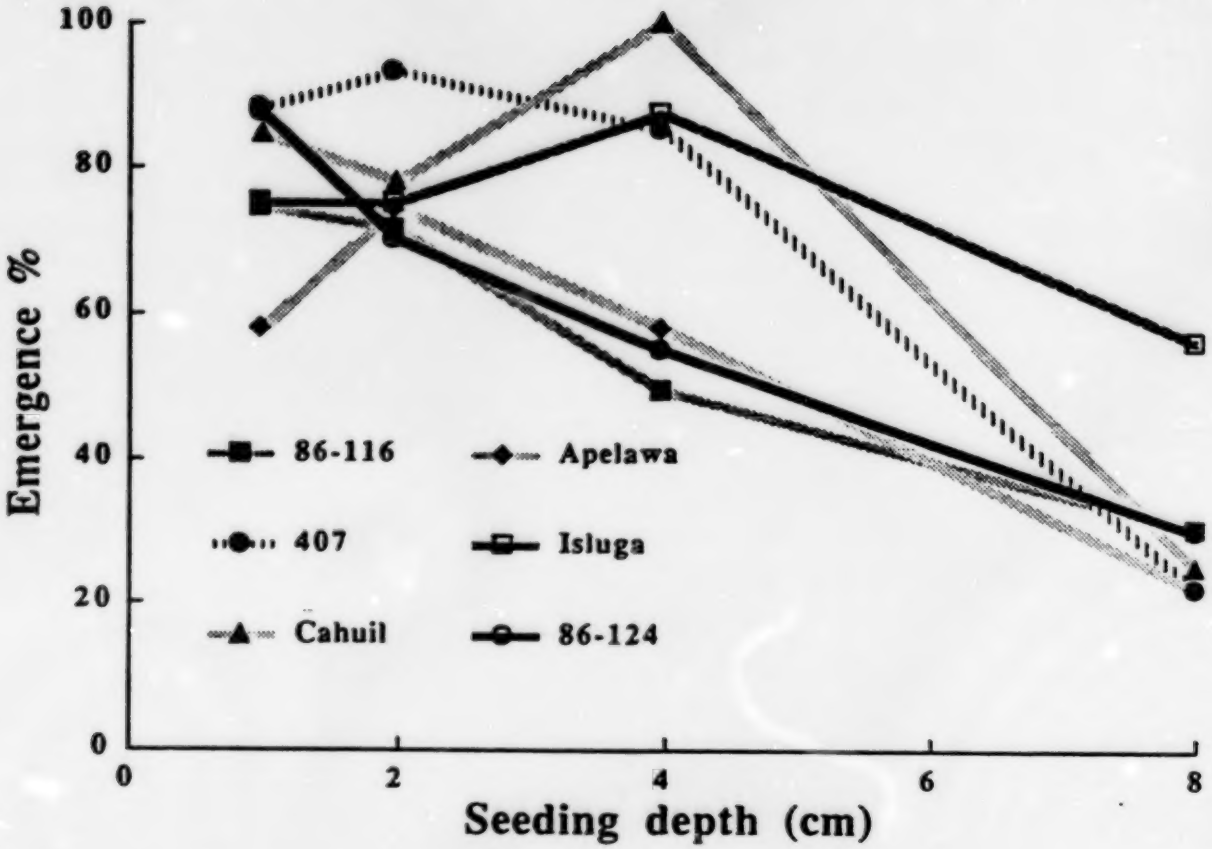


Figure 2. The effect of cultivar and seeding depth on seeding emergence of quinoa grown in the growth chamber.

Discussion

Cultivars which did well in dryland conditionsalso tended to do well in the saline area. Cahuil and 407, the top two dryland producers, also performed well in establishment and production in saline areas. Combined with their strong emergence down to 4 cm, this makes them very favourable varieties. Apelawa, 86-84 and 407-black also did well in both dryland and saline areas. 86-133 and 86-70 were very poor producers in both dryland and saline areas.

In spite of its small seed, quinoa can be planted up to 4 cm deep, in the growth chamber. When soil moisture is poor, establishment may be best at depths approaching 4 cm rather than the 1.5 cm used in the field tests.

Further work. Before quinoa can become a crop in Saskatchewan, we need to know which cultivar to grow, how to grow it, how to process it and where to sell it. At the current time we do not have complete answers to any of these questions. Work is required in all areas.

A definite choice of cultivars can not be made on the basis of two tests in one location, particularly when seed yields were not measured. There are wide differences in the abilities of the

cultivars to grow in the test environments. If these differences are consistent at the other test locations then the less adapted material can be eliminated. Varietal selection will depend on ease of processing, market acceptance and yield and adaptation.

Currently there is some indication that quinoa can be grown in slightly to moderately saline areas. It has high dry matter yields even in dry growing seasons and its reported maturity is short enough for Saskatchewan conditions. A major area of concern in production is stand establishment. Seeding depth has a major influence on stand establishment and the results of the growth chamber work should be confirmed in the field. As weed control methods are not known, stand density and row spacing will play a role in reducing weed competition. It has been suggested that the crop be grown in wide row spacings to allow weed control by cultivation. Work will be required to optimize seeding rate and row spacing.

Quinoa contains bitter flavored compounds. Processing will be required to remove them. The area of processing and market development is essential to the development of quinoa as a crop. Without markets farmers will not grow the crop.

Quinoa seeds germinate relatively quickly. The seeds in some dishes had all germinated within three days. Thus, the germination status as determined by the number of germinated seeds (radicle length >= 5mm) and their relative vigor (rated from a low of 0 to a high of 9) was evaluated and averaged after three days in the germinator (Table 1). Conversion of germination numbers to percent permitted the genetic lines to be arrayed by rank (Table 2). However, each seed-lot might have contained non-viable seeds. Also, the effect of the salt on germination at zero and 18.0 dS/m was assumed nil. Thus, to calculate comparative values indicative of germination in response to salinity, the mean count resulting from the first and second level of salt concentration were averaged and used as a scaling denominator for the remaining counts. This resulted in germination percentages relative to their performance in little or no salt and, as shown in Table 3, permitted the valid salt tolerance ranking amongst the 18 Lines.

Table 1. The number (#) and the vigor of seeds out of 20 which germinated after 3 days, averaged from 3 replicates, listed by genetic line and electrical conductance (EC) of ambient solutions.

	EC of ambient saline solution (dS/m)											
	0		18.0		21.1		24.1		27.6		32.4	
Genetic line	#	vigor	#	vigor	#	vigor	#	vigor	#	vigor	#	vigor
Apelawa	3.7	2.0	0.7	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcha	16.0	6.7	18.3	7.7	18.0	7.7	18.7	7.0	18.3	5.7	14.0	2.7
Kaslala	18.7	8.0	19.0	7.3	17.7	6.0	18.0	6.3	17.7	5.0	14.3	4.6
Pison	18.0	7.3	17.0	6.0	16.3	5.7	17.0	5.0	17.3	5.0	16.7	3.3
Isluga	17.0	6.7	16.3	5.7	17.0	6.0	17.3	5.3	19.3	6.3	15.3	4.0
Cahuil	18.3	7.7	18.0	6.3	18.7	6.7	16.3	6.0	16.3	5.3	15.3	4.0
407-Dave	19.7	8.7	18.7	6.3	17.7	6.0	19.7	5.7	18.3	5.3	17.0	3.3
407-Black	18.7	8.0	18.3	6.0	18.0	6.0	17.0	4.7	16.3	4.3	17.3	3.3
SPS 86-70	9.3	7.3	10.7	4.3	8.3	3.7	10.0	4.0	8.3	4.3	7.6	2.3
SPS 86-72	17.0	8.7	15.0	5.7	14.3	6.7	14.0	4.7	14.7	4.7	14.3	3.3
SPS 86-84	18.7	9.0	19.3	8.0	18.3	7.3	20.0	7.3	19.3	7.0	18.3	5.3
SPS 86-102	17.3	8.0	18.3	5.7	18.0	4.7	16.0	5.3	16.7	4.7	16.3	2.7
SPS 36-116	18.3	8.0	18.3	4.3	15.3	4.3	16.7	3.3	16.3	3.3	16.7	2.3
SPS 86-124	19.7	8.7	19.3	6.3	19.0	6.3	18.3	5.7	18.3	4.3	17.6	3.0
SPS 86-130	15.0	6.3	15.0	5.3	13.7	5.3	15.3	6.0	15.7	5.0	13.0	3.7
SPS 86-133	11.0	4.7	12.7	5.3	9.0	4.0	8.3	2.3	12.3	3.7	8.0	2.3
SPS 87-8	19.0	8.0	17.7	7.0	16.7	6.7	18.0	7.0	16.7	5.7	14.3	3.7
SPS 87-182	17.7	7.3	17.7	6.7	13.0	4.7	16.7	5.0	16.7	5.3	17.0	5.0

Table 2. Average percent germination based on 20 seeds, 3 replications, after 3 days; listed by genetic line (ranked) and electrical conductance (EC) of ambient solutions.

	EC of Ambient Saline Solutions (dS/m)						Rank based
Genetic line	0	18.0	21.1	24.1	27.6	32.4	on EC 32.4 score
SPS 86-84	94%	96%	92%	100%	96%	92%	1
SPS 86-124	98	96	95	92	92	88	2
407-Black	94	92	90	85	82	86	3
407-Dave	98	94	88	98	92	85	4
SPS 87-182	88	88	65	84	84	85	5
Pison	90	85	82	85	86	84	6
SPS 86-116	92	92	76	84	82	84	7
SPS 86-102	86	92	90	80	84	82	8
Isluga	85	82	85	86	96	76	9
Cahuil	92	90	94	82	82	76	10
Kaslala	94	95	88	90	88	72	11
SPS 87-8	95	88	84	90	84	72	12
SPS 86-72	85	75	72	70	74	72	13
Calcha	80	92	90	94	92	70	14
SPS 86-130	75	75	68	76	78	65	15
SPS 86-133	55	64	45	42	62	40	16
SPS 86-70	46	54	42	50	42	38	17
Apelawa	19	4	2	0	0	0	18

Table 3. Average percent germination based on 20 seeds, 3 replications, after 3 days; listed by genetic line (ranked) and electrical conductance (EC) of ambient solutions, derived as ratios of the mean EC=0 and EC=18.0 dS/m values.

	EC of Ambient Saline Solutions (dS/m)				Rank based
Genetic line	21.1	24.1	27.6	32.4	on EC 32.4 score
SPS 86-84	96%	100%	100%	96%	1
SPS 87-182	73	94	94	96	2
Pison	93	97	99	95	3
407-Black	97	92	88	94	4
Isluga	100	100	100	92	5
SPS 86-102	100	90	94	92	6
SPS 86-116	84	91	89	91	7
SPS 86-124	97	94	94	90	8
407-Dave	92	100	100	89	9
SPS 86-72	89	88	92	89	10
SPS 86-130	91	100	100	87	11
Calcha	100	100	100	82	12
Cahuil	100	85	85	80	13
SPS 87-8	91	98	91	78	14
Kaslala	94	95	94	76	15
SPS 86-70	83	100	83	76	16
SPS 86-133	79	73	100	70	17
Apelawa	14	0	0	0	18

Ranking the quinoa lines according to Table 3 provided the fairest appraisal of salt tolerance. This method resulted in SPS 86-84 being ranked as the most salt tolerant of the genetic lines. Some lines, such as Apelawa, perhaps suffered in ranking because of seed viability. The 407-Dave line, which has been recommended for commercial production in Colorado, ranked in the upper half of Table 2 and the median in Table 3. Based on the possibility that 407-Dave might also become commercial in Saskatchewan plus its reasonable ranking, this line and SPS 86-84 were selected for further salt tolerance evaluation, involving shoot biomass growth.

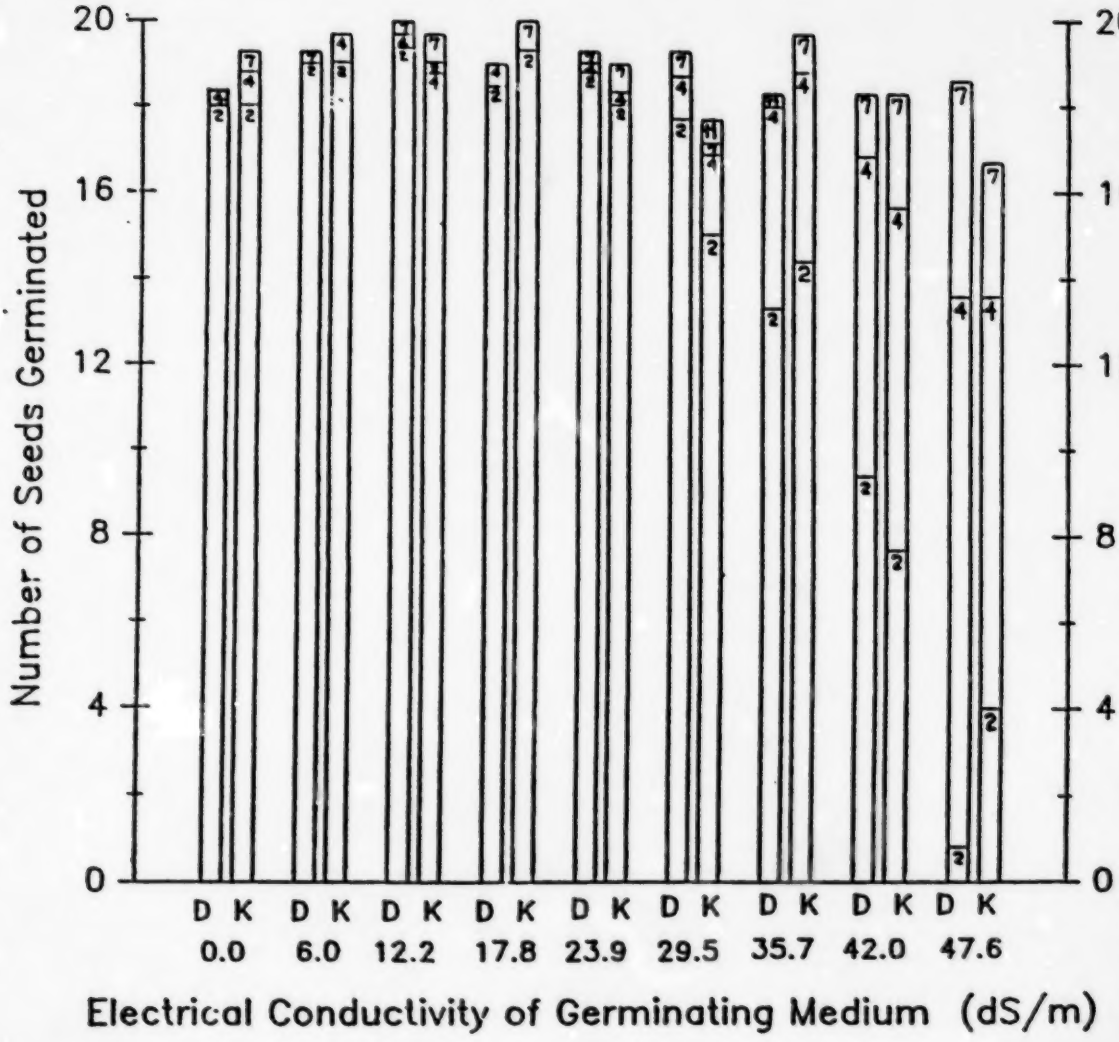
Seed Germination Test

Although the germination of quinoa bathed in various saline solutions was used to screen the available genetic seeds, the full influence of salinity on quinoa germination required further testing. Therefore, an extended germination test was conducted on seeds from two lines: Kaslala and the commercial line, 407-Dave. Kaslala's performance in the screening tests resulted in a relatively low salt-tolerance ranking despite its high initial germination percentage of 94% in the absence of salt. This implied that the Kaslala line might prove especially susceptible to reduced germination when confronted with saline soil conditions. The second test would require an extended time period to determine definitely whether salty soil solutions would or would not inhibit germination.

The experimental procedure followed that conducted in the screening tests except that nine instead of six salt levels were used with concentrations of up to 47.6 dS/m. Each concentration was replicated three times and was formed from equal mass additions of sodium and calcium chlorides. Each petri dish contained twenty seeds placed on thick filter paper. Before placement, all seeds were sterilized in sodium hypochlorite solutions under vacuum. Petri dishes were arranged completely random on the floor of the germinator. The test commenced on February 12, 1990 lasting 11 days, with the germinator set for a constant 20^{o}C, 12 hour days (low light intensity), and 95% relative humidity.

The extended germination test proceeded as planned, terminating on the 23rd of February, 1990. The number of germinated seeds and their relative vigor (scale 0 to 9) were observed after 2, 4, 7 and 11 days in the germinator. Figure 1 presents the accumulated number of 407-Dave and Kaslala quinoa seeds germinated at each salinity level during the test. As in the screening tests, the germination rate of 407-Dave exceeded that of Kaslala at the higher salinity levels, although total germination numbers of the two lines exhibited much less divergence at the end of the experiment. The figure also shows a tendency toward sluggish germination in both lines as the salinity of the ambient media increases. This might suggest that salinity lowers the osmotic gradient between the seed and its surrounding solution, reducing the rate at which water moves into the seed. Eventually, sufficient water does enter the seed for the initiation of cell division and growth. The result is delayed but eventual germination as evidenced in Figure 1.

Figure 1. Ave. number of germinated quinoa seeds (D=407Dave; K=Kaslala) after 2, 4, 7 or 11 days in salt solutions of increasing Elec. Cond.


Number of Seeds Germinated
20
16
12
8
4
0
D K D K D K D K D K D K D K D K D K
0.0 6.0 12.2 17.8 23.9 29.5 35.7 42.0 47.6
Electrical Conductivity of Germinating Medium (dS/m)

Shoot Biomass Test

Barley is classed as salt tolerant and is often seeded for a grain crop in saline soils. Quinoa also produces a grain crop, which can provide an alternative to barley in saline environments, if it also tolerates salt. Space in the mature-plant testing-wing of the Salt Lab permitted simultaneous evaluation of three crops during one growth cycle. The logical choice among the test plants included the quinoa lines identified from the screening process, namely SPS 86-84 and 407-Dave, plus a common barley variety, Harrington. The objective was to measure the yield of the above-ground or shoot biomass and any grain produced in response to increasing levels of salinity. Analyses of these data would lead to salt tolerance functions for the three test lines.

As described in Appendix 1 to this report, the mature plant testing component of the Swift Current Salt lab provides hydroponic sand-tank media for growing crops under irrigation with waters of any selected salt concentration. Preparation for the quinoa test included disinfecting the sand tanks and system with sodium hypochlorite followed by repeated rinsing with tap water. The sand consists of 99.8% pure silicon-dioxide particles ranging in size to have a water-holding capacity of 25-30% by volume. Set points for controlling ambient temperature during the test centered on 21°C during the time between 09:00 and 21:00 and on 19°C for the remaining 12 hours of each day. Daylength was adjusted with supplemental light derived from high-power, sodium-vapor lamps. Light was arranged to mimic daylengths at 52 degrees north latitude and a seeding date of May 13th. Simulated daylengths began with 15.5 hours, increased to 16.6 hours as if during spring solstice, and declined to 14.5 hours at harvest.

Seeds were individually placed in each sand tank to a depth of 1 cm for quinoa and 3 cm for the barley on November 16, 1989. Tank selections for seeding each test line were randomized with respect to six salt levels replicated three times. Preparation of the hydroponic supply tanks consisted of nutrient additions to analyzed tap water quantified according to Prairie greenhouse recommendations. The seeds were automatically irrigated daily at 09:00, 14:00 and 19:00 hours. Quinoa began to emerge on the fourth day with barley visible two days later. Targeted plant densities for the quinoa and the barley equaled 35 and 67 plants per square metre, respectively.

Salts were added to the hydroponic supply tanks according to the randomized plan for each test crop, salt level and replication. Equal masses of sodium and calcium chloride were mixed to give target solution electrical conductivities of 0.8 (tap water only), 10, 18, 26, 32 & 40 dS/m for each quinoa line and 0.8, 10, 15, 20, 26 & 30 dS/m for the barley. One-third of the total for each tank was added on day 20 of the test when the quinoa averaged 8 cm in height and showed six true leaves, and the barley was in the 3-leaf stage. The second 1/3-addition of salt followed a week later (day 27), and the final third on day 36. The final addition also included 2 g/l of the chloride mix to those tanks initially targeted for the lowest salt concentration. This increased the salinity of these solutions from 0.8 to 6.2 dS/m. Despite care in replacing water removed by evapotranspiration and prevention of solute precipitation, the measured EC-values of the hydroponics during the test averaged 6.2, 11.5, 18.5, 25.0, 30.0 & 36.0 dS/m for the quinoa, and 6.2, 11.5, 16.0, 20.5, 25.0 & 28.5 dS/m for the Barley.

The designed environmental conditions appeared to favor growth in both quinoa lines and the barley, except for the expected stunting at the higher salt levels. The barley was in the 5-leaf stage 30 days following seeding, while the quinoa at that time showed about 12 true leaves. Quinoa floral development was evident after 50 days, followed by the emergence of the barley floral spikes 12-15 days later. Heights of the plants not subjected to excessive salts averaged 89 cm for barley and 106 cm for quinoa on day 60. A fourth irrigation at 24:00 hour each day was included beginning the 72nd day after seeding. Typical of an indeterminate type of plant growth, quinoa continued to produce new shoots and leaves as the deadline for harvest neared. It became evident that validly comparable grain yields would not be possible, leaving comparisons between plant height and shoot biomass as the lone measures of salt tolerance.

Harvest began on day 96 and extended into the next day, February 21, 1990. Table 4 summarizes plant heights observed at harvest. Besides favoring the lower salt concentrations, quinoa heights demonstrate the tendency for irrigation to promote vegetative growth rather than seed development in this type of plant. Shoot biomass weights were taken immediately upon harvest (Table 5) and after low-heat oven-drying (Table 6). The ratios of dry to wet weights tabulated in Table 7 show significantly greater overall water content in the quinoa tissue compared to that of the barley. Also, ratios tend to increase with increasing salinity in the barley, but not in either quinoa line.

Table 4. Average above-ground plant heights (cm) at harvest; listed by genetic line and electrical conductivity (EC = dS/m) of irrigated hydroponic solution.

EC	407-Dave quinoa	SPS 86-84 quinoa	Harrington barley
dS/m	cm	cm	cm
6.2	190	190	113
11.5	169	170	92
16.0			85
18.5	162	162	
20.5			80
25.0	135	140	70
28.5			63
30.0	120	134	
36.0	93	104	

Table 5. Average weight of shoot biomass (g) at harvest before oven-drying; listed by genetic line and electrical conductivity (EC = dS/m) of irrigated hydroponic solution; (multiply by 12 to obtain kg/ha).

EC	407-Dave quinoa	SPS 86-84 quinoa	Harrington barley
dS/m	g	g	g
6.2	7766	7268	2860
11.5	5523	7261	1763
16.0			1649
18.5	5371	6535	
20.5			1217
25.0	4257	4087	877
28.5			663
30.0	3951	3114	
36.0	2710	2328	

Table 6. Average weight of shoot biomass (g) at harvest after oven-drying; listed by genetic line and electrical conductivity (EC = dS/m) of irrigated hydroponic solution; (multiply by 12 to obtain kg/ha).

EC	407-Dave quinoa	SPS 86-84 quinoa	Harrington barley
dS/m	g	g	g
6.2	1383	1313	531
11.5	1072	1136	468
16.0			450
18.5	926	1055	
20.5			368
25.0	771	707	280
28.5			203
30.0	661	546	
36.0	456	416	

Table 7. Average ratio of dry/wet weights of shoot biomass; listed by genetic line and electrical conductivity (EC = dS/m) of irrigated hydroponic solutions.

EC	407-Dave quinoa	SPS 86-84 quinoa	Harrington barley
dS/m			
6.2	0.18	0.18	0.23
11.5	0.20	0.16	0.27
16.0			0.27
18.5	0.17	0.16	
20.5			0.30
25.0	0.18	0.17	0.32
28.5			0.31
30.0	0.17	0.18	
36.0	0.17	0.18	

Table 6 includes the data necessary to determine the salt tolerance function based on the shoot biomass produced by each test crop. Biomass values at the lower salinities of 6.2 and 11.5 dS/m were averaged in order to determine the quantity of shoot dry matter which was produced when the influence from salinity was at a minimum:

for 407-Dave, 1227 g per tank (14.72 t/ha);
for SPS 86-84, 1224 g per tank (14.69 t/ha);
for Harrington, 500 g per tank (6.00 t/ha).

Relative shoot yields for each test crop, expressed as a percentage of the minimum salinity value (1227, 1224 & 500g), were calculated for the production resulting from the plant growth in each level of salinity tested (Table 8).

With four pairs of biomass/EC data for the barley and five pairs for each quinoa from Table 8, linear regressions established the positions and slopes of the declining yield with increasing salinity for each test crop. Threshold EC values equaled the point of intersection of the regression line and the 100% yield level, and were computed from the regression equations solved for the EC when yield equaled 100%. These procedures contribute the information necessary to evaluate the Maas and Hoffman (1977) type response functions from the salt tolerance test,

$$Y = 100 - \text{slope}\ (EC - \text{threshold}),$$

where the relative yield, Y, is in percent, and the electrical conductivity of the test solution is in dS/m. Evaluated for:

407-Dave: $Y = 100 - 2.01\ (EC - 5.94)$,
SPS 86-84: $Y = 100 - 2.62\ (EC - 10.13)$,
Harrington: $Y = 100 - 3.95\ (EC - 13.47)$.

Confidence intervals and paired-t tests associated with these salt tolerance responses indicate that the barley equation is statistically different from either quinoa function; however, the tests failed to accept the hypothesis of a statistical difference between the two quinoa responses.

Table 8. Average percent reduction in oven-dried shoot biomass of Harrington barley and Quinoa (407-Dave and SPS 86-84) grown from irrigated hydroponics with test salt concentrations of the listed electrical conductivity (EC = dS/m).

EC	407-Dave quinoa	SPS 86-84 quinoa	Harrington barley
dS/m	%	%	%
6.2	100.0	100.0	100.0
11.5	87.3	92.8	100.0
16.0			90.0
18.5	75.5	86.2	
20.5			73.7
25.0	62.8	57.8	55.9
28.5			40.5
30.0	53.9	44.6	
36.0	37.2	34.0	

The salt tolerance response functions together with data points averaged from the three test replications are graphed in Figure 2. These data indicate that beyond their respective thresholds quinoa shoot production of the two genetic lines, 407-Dave and SPS 86-84, react less negatively to increasing root-zone salinity than the reaction from Harrington barley. That is, the Harrington salt tolerance slope is steeper than either quinoa line. However, the threshold EC of barley is also greater, equaling 13.5 dS/m compared to 10.1 and 5.9 dS/m for SPS 86-84 and 407-Dave.

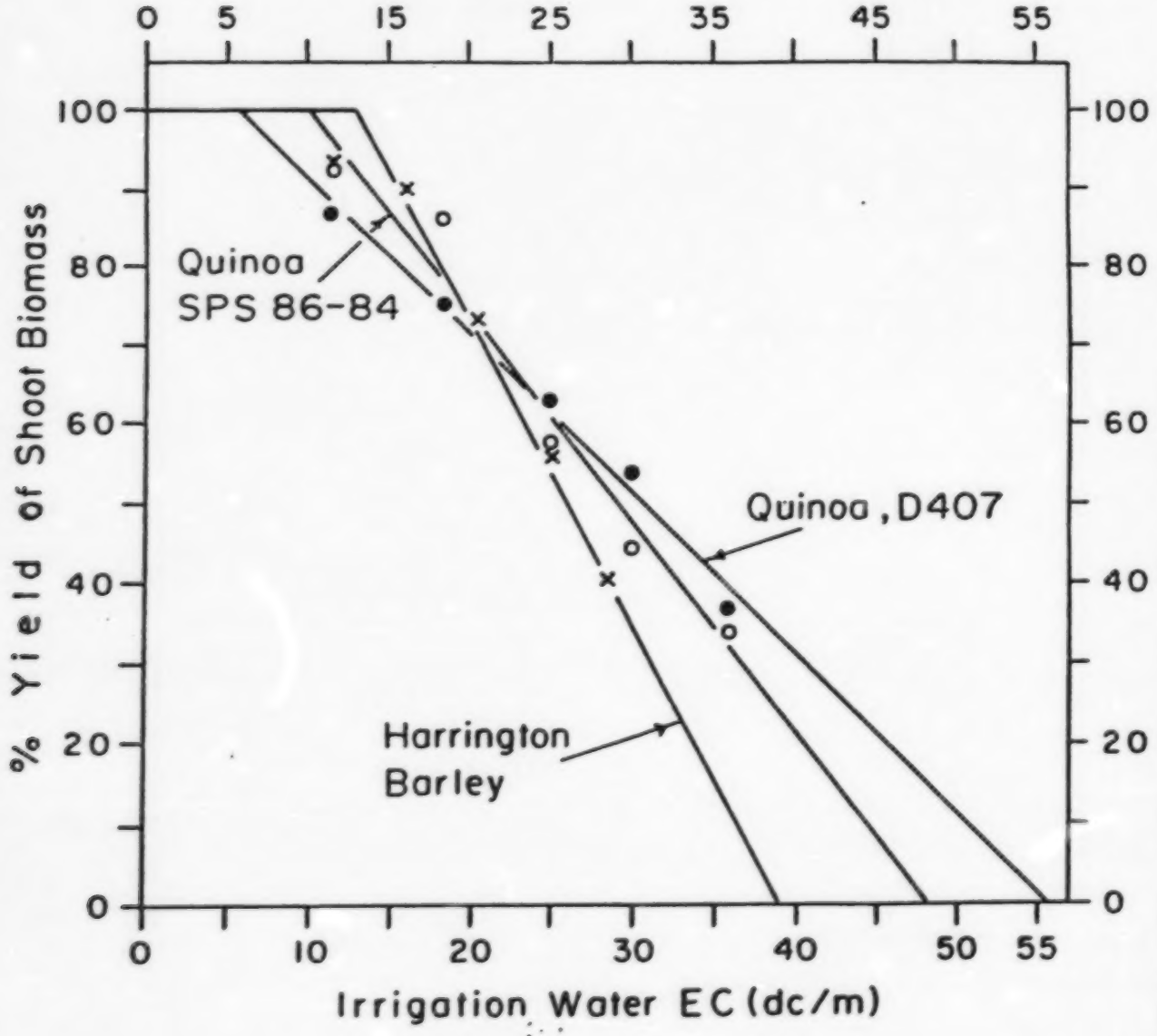
The functions outlined in Figure 2 suggest both encouragement and caution in offering quinoa as a potential salt tolerant crop. On the positive side, representatives of the species can be expected to thrive better than the barley in soils whose biomass yields have been reduced by salt 30% or more than the non-saline production. The yield reduction Table 9 shows the 30% reduction occurring at a soil extract of ECe 10 or 11 dS/m. As ECe increases, the tolerance potential for quinoa also appears to increase; for example, biomass growth of the two lines extend the 50% yield value 2 dS/m beyond that for Harrington barley. The caution, however, relates to soils showing slight to moderate salinity, especially below the 7 dS/m threshold ECe which favors barley. The inference is that relative crop production from quinoa will lag that from barley in those sites where salinity is just beginning (or ending) and where large areas of a saline site exist in the transition from zero to severely saline.

Table 9. Predicted electrical conductivity of the soil solution (ECsw) and saturated paste extract (ECe) resulting in the specified percentage reductions of shoot dry-matter yields for three test crops.

Yield reduction in shoot biomass	Test Crop					
	407-Dave quinoa		SPS 86-84 quinoa		Harrington barley	
%	ECsw	ECe	ECsw	ECe	ECsw	ECe
	dS/m					
0	6	3	10	5	14	7
10	11	5	14	7	16	8
20	16	8	18	9	19	9
30	21	10	22	11	21	11
40	26	13	25	13	24	12
50	31	15	29	15	26	13
60	36	18	33	17	29	14
70	41	20	37	18	31	16
80	46	23	41	20	34	17
90	51	25	44	22	36	18
100	56	28	48	24	39	19

Assumption: ECsw = 2ECe

Figure 2. Salt tolerance responce functions for two genetic lines of quinoa (407-Dave & SPS 86-84) and for Harrington barley, where the relative yield (%) of shoot biomass (dry matter) is expressed as a linear function of sand-cultured, hydroponic salt solutions at increasing electrical conductivities (EC).



Dryland Study

. The Texas kochia produced significantly more dry matter than all quinoa varieties or crosses (Appendix III, Table 1). Co407, Cahuil, SPS 86-72, Pison, Apelawa, and Calcha produced the most dry matter and SPS 87-8, SPS 86-116, SPS 87-182, SPS 86-133, and SPS 86-70 were low producers in 1989.

Salinity Study

Texas kochia was significantly more capable of establishment and production in saline soils than any quinoa variety (Appendix III, Table 2). Quinoa varieties differed in their ability to establish and to produce under various salinity levels with Co407, SPS 86-84, Co407-black, Cahuil, SPS 86-124, and Pison showing the highest production in the saline area. Isluga, SPS 87-8, SPS 86-116, SPS 87-182, SPS 86-133, and SPS 86-70 were the lowest dry matter producers.

Cultivars, such as Cahuil and Co407, which did well under dryland conditions also tended to do well in the saline area. They also showed strong emergence when planted at a depth of 4 cm even though their seed was very small. Establishment may be better at this depth when soil moisture is poor.

Emergence Study

Plant height and emergence was affected indirectly by seeding depth and also by cultivar (Appendix III, Tables 3 and 4). As expected, emergence decreased as seeding depth increased, particularly at the 8 cm depth (Appendix

Conclusions and Recommended Future Tests

The tests reported in this study indicate that quinoa tolerates saline environments relatively well. The two genetic lines tested, (407-Dave & SPS 86-84), showed relatively greater shoot-biomass production in salinities greater than those causing yield reductions of 30% or greater. Thus, expect quinoa to grow better than barley in the more saline soils. That is, if Harrington barley and 407-Dave quinoa are seeded in parallel rows along an increasing salt gradient, look for greater shoot dry-matter, relative to the non-saline production, from the quinoa than from the barley as salinity increases past an ECe of around 11 dS/m. The test data indicate that quinoa plants will survive further into the salt than most barley specimens.

Barley, on-the-other-hand, still seems to possess the ability to grow without any reduction in biomass yield up to a greater salinity level or threshold than quinoa before production begins to decline. This inference implies that barley remains the grain of choice in slightly and moderately saline soils. Nonetheless, if biomass production is any indication, quinoa shows potential as an alternate grain crop for saline soils with an average ECe of 10 dS/m or greater.

Realization of quinoa's potential will require additional testing, including further salt tolerance evaluations. Obviously, quinoa's response in seed yield as a function of salinity is essential. Also, information relating seedling emergence and plant establishment under saline conditions should be determined. To ascertain true genetic responses, both tests must be conducted under controlled conditions where rootzone salt concentrations will remain spatially uniform and temporally constant throughout each test.

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